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Learning Environment, Attitudes and Achievement among Middle-school Science Students Using Inquiry-based Laboratory Activities

Stephen J. Wolf · Barry J. Fraser

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Abstract This study compared inquiry and non-inquiry laboratory teaching in terms of students' perceptions of the classroom learning environment, attitudes toward science, and achievement among middle-school physical science students. Learning environment and attitude scales were found to be valid and related to each other for a sample of 1,434 students in 71 classes. For a subsample of 165 students in 8 classes, inquiry instruction promoted more student cohesiveness than non-inquiry instruction (effect size of one-third of a standard deviation), and inquiry-based laboratory activities were found to be differentially effective for male and female students.

Keywords Attitudes · Achievement · Inquiry · Laboratory teaching · Learning environment · Middle schooling

Introduction

Students are encouraged through national education standards (Hayden et al. 2004; National Research Council 1996; NCLB 2001) to be engaged in the learning process, particularly through group work and hands-on activities. It is recommended that students' existing knowledge is accounted for and built upon or adapted (Hess and Trexler 2005; Sewell 2002), that students support conclusions with evidence and observations, and that students are encouraged to share and discuss ideas with peers. During this process, the teacher acts as a guide who challenges the students to think beyond their current processes by offering divergent questions (Alesandrini and Larson 2002; Windschitl 2002). The teacher facilitates appropriate discussion and helps students to focus on experimental data and facts (Baker and Leyva 2003). These practices are collectively known as inquiry-based teaching and learning.

S. J. Wolf · B. J. Fraser (✉)
Science and Mathematics Education Centre, Curtin University of Technology, GPO Box U 1987, Perth 6845, Australia
e-mail: b.fraser@curtin.edu.au

One of the key issues associated with the use of inquiry is the need for time. Most inquiry exercises span several class sessions and can continue for weeks at a time (Erdogan 2005; Krajcik et al. 1998). But this conflicts with state and national requirements to complete core curricula. Therefore the creation and use of small-scale inquiry activities that challenge students and prove to be effective would be beneficial and timely. Therefore, the inquiry activities used in our study, which each require only 1 to 2 days for completion and utilize the key aspects of inquiry, are significant. But, it was important to evaluate this inquiry instruction, including a comparison of an inquiry group with a non-inquiry group.

Prior studies have supported the effectiveness of inquiry-based programs, but have not compared results with those of non-inquiry activities (Abell 1999; Erdogan 2005; Krajcik et al. 1998; Schlenker and Schlenker 2005). Such studies could further suggest changes to educational standards and practices. If inquiry-based learning can improve student outcomes in physical science, then similar strategies could work in other subject areas and for other age groups. The reduction of the amount of time required to carry out small-scale laboratory activities allows more inquiry to be introduced into the classroom.

This study was initiated to evaluate the effectiveness of using inquiry-based laboratory activities among Grade 7 students in terms of the classroom learning environment and student attitudes to and achievement in physical science. As well, we investigated the differential effectiveness of inquiry activities for male and female students.

Research Questions

1. In what ways is inquiry-based laboratory teaching effective in terms of classroom learning environment, students' attitudes to science and students' science achievement?
2. In what ways is inquiry-based laboratory teaching differentially effective for males and females in terms of classroom learning environment and student attitudes and achievement?
3. What associations exist between the nature of the classroom learning environment and student attitudes and achievement?

Theoretical Framework

Learning Environments Research

The current field of learning environments has been shaped by several influential figures over the years. Lewin (1936) initiated the idea that personal behaviour is a result of the interaction between the individual and his/her environment. Murray (1938) expanded upon this idea by considering additional effects within the system, namely, that an individual's behavior is affected internally by characteristics of personality and externally by the environment itself. The individual's interaction with the environment relates to the personal needs of the individual. This was later expanded by Stern et al. (1956), who concluded that differences also exist between an individual's perceptions, a group's perceptions, and the perceptions of an external observer of a single environment.

Herbert Walberg and Rudolf Moos independently examined participant perceptions of various learning settings (Moos 1974, 1979; Walberg 1979; Walberg and Anderson 1968). Research and evaluation related to Harvard Project Physics led Walberg and Anderson (1968) to develop the Learning Environment Inventory (LEI). Moos (1974) developed a

scheme for classifying human environments into three dimensions (relationship, personal development, and system maintenance and change) to enable the classification and sorting of various components of an environment. This led Moos to the development of the Classroom Environment Scale (CES) (Moos 1979; Moos and Trickett 1974), which linked his work in other human environments to school settings.

Following the pioneering research of Walberg and Moos in the USA, two further programs of learning environment research emerged, one in the Netherlands and one in Australia. In the Netherlands, Wubbels and his colleagues began ambitious programmatic research focusing specifically on the interaction between teachers and students in the classroom and involving use of the Questionnaire on Teacher Interaction (QTI; Fraser and Walberg 2005; Wubbels and Brekelmans 1998; Wubbels and Levy 1993). Subsequently, research on teacher-student interaction involving use of the QTI has spread to numerous countries including Korea (Kim et al. 2000), Brunei (Scott and Fisher 2004), Singapore (Goh and Fraser 1998; Quek et al. 2005) and Australia (Henderson et al. 2000).

In Australia, Fraser and his colleagues began programmatic research which first focused on student-centred classrooms and involved use of the Individualised Classroom Environment Questionnaire (ICEQ; Fraser 1980, 1990). Subsequently, other specific-purpose instruments were developed, validated and applied for a variety of research purposes around the world. In particular, these questionnaires include the Science Laboratory Environment Inventory (SLEI; Fraser et al. 1995; Henderson et al. 2000; Lightburn and Fraser 2007; Wong and Fraser 1996), Constructivist Learning Environment Survey (CLES; Kim et al. 1999; Nix et al. 2005; Spinner and Fraser 2001; Taylor et al. 1997) and the What Is Happening In this Class? (WIHIC) used in the present study (Aldridge et al. 1999; Dorman 2003; Fraser and Chionh 2000; Ogbuehi and Fraser 2007).

There have been numerous classroom environment studies conducted around the world with a variety of purposes over the past 30 years (Fraser 1998a,b; Goh and Khine 2002). A strong theme in past classroom learning environment research has involved investigations into associations between students' cognitive and affective learning outcomes and their perceptions of psychosocial characteristics of their classroom environments (Fraser and Fisher 1982; Haertel et al. 1981; Lawrenz 1976; McRobbie and Fraser 1993; Simpson and Oliver 1990; Talton and Simpson 1987). Numerous studies have shown that students' classroom environment perceptions, relative to students' background characteristics, are more closely associated with learning outcomes. For example, the What Is Happening In this Class? (WIHIC) questionnaire (Aldridge et al. 1999; Fraser et al. 1996) has been utilized in conjunction with the Test of Science-Related Attitudes (TOSRA; Fraser 1981) to examine associations between the learning environment and students' affective and cognitive outcomes in numerous studies with large samples of students around the world (Aldridge et al. 1999; Khine and Fisher 2001; Koul and Fisher 2005; Telli et al. 2003; Zandvliet and Fraser 2004, 2005).

Learning environment assessments have been used in educational productivity research (Fraser et al. 1986, 1987a; Walberg et al. 1986) and in the evaluation of educational innovations (Dryden and Fraser 1996; Fraser et al. 1987b; Lightburn and Fraser 2007; Khoo and Fraser 2007; Maor and Fraser 1986; Teh and Fraser 1994). Links between educational environments have also been explored (Dorman et al. 1997; Fraser and Rentoul 1982; Marjoribanks 1991; Moos 1991). Cross-national studies have also been conducted to explore educational practices, beliefs and attitudes that differ between countries, and which could lead to suggestions for improving educational practices or identifying unique cultural characteristics of each location (Aldridge and Fraser 2000; Aldridge et al. 1999, 2000; Dorman 2003; Dorman et al. 2003; Farenga and Joyce 1997a).

Inquiry-based Learning

During inquiry, student social interaction is high, and therefore students must work in a risk-free environment (Brewer and Daane 2002) where they are encouraged to ask questions, share ideas and engage in dialogue. Inquiry requires students to be positively interdependent, so that the benefit to one student benefits the whole group (Colburn 1998). Students must be held personally accountable for the information obtained in the activity, and therefore they should be individually assessed. All students must participate equally and simultaneously to ensure equal opportunities for all students (Dalton and Morocco 1997; Mastropieri et al. 2001).

Krajcik et al. (1998), in reporting a 7-month study performed in seventh-grade inquiry-based settings involving the decomposition of garbage, comment that students experienced difficulty in formulating appropriate questions that focus on the intended content of the work. As in other studies (Abell 1999; Brewer and Daane 2002), student interactions were high, especially for competitive measures for which students would investigate what others were doing to solve the problem. Students overall seemed motivated in the exploration process. A key element to the process was the involvement in teacher questioning to propel students in wider directions (Krajcik et al. 1998). This is consistent with findings from Abell's (1999) four stories of questioning practices, Colburn's (1998) reflection upon the impact of questioning during inquiry, and Dalton and Morocco's (1997) examination of inquiry-based practices among students with learning disabilities.

As can be seen in these examples, the use of inquiry while instructing students helps them to develop a new process for learning (Beisser and Gillespie 2003). The students use questioning techniques, exploration and reflection as key parts of their inquiry process (McVarish and Solloway 2002). In using inquiry, however, it is important to note that not all goals will necessarily be achieved (Mintrop 2001). Missing from these prior studies is evaluation of the effectiveness of inquiry in terms of content retention. The students engaged in these studies re-evaluated their basic beliefs and sought new solutions, as suggested by Colburn (1998). In our study, we evaluated inquiry instruction in terms of the learning environment and students' attitudes and achievement.

Long-term investigations, such as those on decomposition of garbage (Krajcik et al. 1998), volcanism (Erdogan 2005), and fish communication (Schlenker and Schlenker 2005), require vast amounts of class time to support the entire process. Each of these activities is centred on solid content and helps students to learn and explore the topics in a manner similar to scientists. However, the time needed for these activities reduces the time otherwise available for covering other required curriculum goals. While state assessments focus on content over process (Bennett et al. 2005), a balance must be established. The current study investigated the effectiveness of small-scale inquiry-based activities that only require 1 to 2 days for execution.

Gender Issues

The current study explored whether the use of inquiry-based methods is differentially effective for male and female students in terms of student perceptions of the learning environment, attitudes toward the class, and achievement in physical science. Past research suggests that few differences exist between primary school males and females in terms of attitudes toward science (Alexakos and Antoine 2003) and that gender differences are more likely to manifest themselves in the middle-school years (National Center for Education

Statistics 2000), although perceptions toward science can begin developing before the age of 9 years (Joyce and Farenga 1999).

Farenga and Joyce (1997a,b) reported that males were more likely to fix objects, build models, and seek action-oriented activities, as well as to listen to science news and read science books and magazines. Females focused on life science activities outside the classroom, particularly the nurturing and caring of animals and plants, and were likely to collect and catalogue leaves and shells. The study suggests that males and females naturally undertake science-related activities at home, at least at an early age.

Gender gaps in academic performance have been found to increase throughout the secondary school (National Center for Education Statistics 2000). When Bacharach et al. (2003) studied achievement gaps across racial and gender groups among graduating students traced back from Grade 8, gaps were shown to increase between black and white students and between male and female students. The average yearly increase for academic achievement among males was greater than that for females. By tenth grade, female attitudes toward science were reported to become increasingly negative (Alexakos and Antoine 2003).

By utilising inquiry methods, females and males are provided with opportunities to explore and support their own ideas, within the constraints of the curriculum. Males can benefit from interactions with the thought processes of females, while females can benefit from the confidence of the males (Lee 2003). The present study investigated the differential effectiveness of inquiry and non-inquiry teaching techniques for females and males in terms of learning environment, attitudes and achievement.

Methods

This study took place in four main stages. A pilot study was first conducted to ensure the readability of the instruments by middle-school students. A larger sample, called the 'external' sample, responded to the instruments to provide a large data base for checking the validity and reliability of questionnaires. A smaller sample, which was called the 'internal' sample and was part of the external sample, engaged in two alternative forms of laboratory instruction for six consecutive laboratory exercises. After the treatment period, a group of students was interviewed for qualitative feedback.

Assessment Instruments

Student perceptions of the classroom learning environment were assessed using the What Is Happening In this Class? (WIHIC) questionnaire (Aldridge et al. 1999; Fraser et al. 1996), which assesses the seven dimensions of Student Cohesiveness, Teacher Support, Involvement, Investigation, Task Orientation, Cooperation, and Equity. The WIHIC has been validated in several countries, at different grade levels, and across different disciplines, including with 2,310 students in Singapore (Fraser and Chionh 2000), 1,173 Canadian students in mathematics and science classes that use laptop computers (Raaflaub and Fraser 2002), 2,498 Indonesian university students (Margianti et al. 2004), 1,021 students in 32 classes in India (Koul and Fisher 2005), 543 Grade 8 science students in Korea (Kim et al. 2000), 525 university students in the USA (Martin-Dunlop and Fraser 2007), and junior high schools samples of 1,879 students in Taiwan and 1,081 students in Australia (Aldridge and Fraser 2000; Aldridge et al. 1999). When Dorman (2003) and Dorman et al. (2003) conducted a cross-national validation of the WIHIC among 3,980 Grade 8, 10, and 12

students from Australia, the UK, and Canada, confirmatory factor analysis using six different indices showed good model fit with the data.

Student attitudes toward science were assessed using a modified version of selected items from the Test of Science-Related Attitudes (TOSRA) (Fraser 1981). Specifically, these items were chosen from and based on TOSRA's Enjoyment of Science Lessons scale, but modifications were made to avoid repetition and any negatively-worded, reverse-scored items.

Achievement was measured quantitatively with a nine-item scale written to assess conceptual knowledge of basic physical science concepts. The questions were developed based on the New York State Intermediate-Level Science Test (Bennett et al. 2005) and included a basic range of topics with diagrams and a multiple-choice format. Qualitative data were also collected during teacher commentaries of student performance on the laboratory activities, questions, and class discussions.

Samples

In order to ensure that the WIHIC and modified TOSRA, which were originally created and validated in Australia, were suitable for use with students in the current study in the United States, we collected data from a large number of students. Volunteer teachers from various schools in New York and in seven other states administered the questionnaires to their students. This provided a large data set of 1,434 students located in 71 classes. Fourteen (14) schools were public schools and 4 were private schools. All schools were coeducational and had a relatively even mix of males and females. Students in the external sample schools also had a diverse range of socioeconomic and ethnic backgrounds.

In order to compare inquiry and non-inquiry laboratory techniques, different students experienced laboratory activities in different ways. For 8 weeks, a subsample of 165 students in 8 seventh-grade physical science classes participated in an action research study within a single middle school located in Long Island, New York. Two teachers each taught four classes, two with inquiry laboratory activities and two with non-inquiry laboratory activities. Students conducted several laboratory experiments based on the physical science curriculum. Both laboratory activity styles focused on similar content, though the processes varied greatly.

The first researcher's school was selected for use in the internal study, allowing him and a colleague to carry out this part of the study personally. The school is primarily composed of Caucasian students. There were eight classes in the entire seventh grade in the internal study school, with a total of 178 students taught by the two teachers. The inquiry and non-inquiry groups were selected so that they were of similar academic strength, which was verified using a *t*-test for independent samples to ensure that the groups were not statistically significantly different before treatment in terms of achievement on a content examination. Absenteeism from the survey administration brought the total sample down to 165 students.

Instructional Methods

The inquiry laboratory activities were small-scale, which involved the major characteristics of inquiry, such as challenging students to develop and plan their own investigations, working collectively toward unique goals, and sharing individual findings, without requiring vast amounts of classroom time for such investigations. Aside from the differentiated laboratory styles and resulting discussions, all other classroom interactions

were kept consistent, including homework assignments, class notes, examinations and practice sheets. All students were responsible for the same content material.

Inquiry and non-inquiry activities differed in their presentation. Students in the inquiry classes were given a set of materials and a challenge question or statement, such as ‘explore static electricity’, whereas the students in the non-inquiry classes were given detailed instructions to follow. The inquiry students needed to design controlled experiments and decide upon appropriate data to collect, as well as to tabulate their findings. In the non-inquiry classes, the procedure involved a set process, with data tables being provided for students to complete with their findings. Both groups were challenged to answer questions based on their findings, such as ‘What materials were needed to create static electricity in this lab?’ For both groups, each activity lasted only one class period (except for the Aspects of Light activity which spanned 2 days), discounting class discussions that ensued on the following day.

Interviews

Tobin and Fraser (1998) recommend combining quantitative and qualitative methods in learning environment research in order to enhance the comprehensibility and usefulness of results. The final phase of our study involved gathering qualitative data based mainly on student interviews. Duit and Confrey (1996) and Carr (1996) suggest that interviews can be used to offer a more complete picture of students’ thought patterns than can diagnostic testing. Guided by the recommendations of Erickson (1998) and Denzin and Lincoln (1994), interview questions were written to be open-ended and non-biased, allowing students to comment on personal experiences without being ‘led’ by the questions. Interviews were conducted in the internal school among students who were involved in the study to complement the quantitative data obtained from WIHIC, TOSRA and achievement scales. Twenty (20) students received parental permission and participated in the interviews. Twelve students were in the inquiry group and eight students were in the non-inquiry group. Students in each group were of different genders and academic abilities. Because parental permission did not include audio- or video-taping of responses, interview statements were directly transcribed during the group sessions. The students were highly cooperative in allowing transcription of their statements. The two teachers involved in the study also noted differences in in-class interactions between students in the inquiry group and students in the non-inquiry group.

Results

Validity and Reliability of WIHIC and TOSRA Scales

Before using data from the WIHIC and TOSRA to investigate the study’s main research questions, it was important to check their validity and reliability when used with middle-school physical science students in New York. WIHIC, modified TOSRA, and achievement data were available from 1,434 middle-school students in 71 classes. Principal axis factoring with oblique rotation was used to examine the internal structure of the original 56-item, seven-scale version of the WIHIC when used with United States middle-school students located primarily in New York. For a 52-item version (with Items 16, 18, 29, and 33 removed), each item had a factor loading of at least 0.30 on its a priori scale and less than 0.30 on every other scale (Table 1). The percentage of variance ranged from 1.71 to 33.52% for different scales, with a total variance

Table 1 Factor loadings for the WIHIC (principal axis factoring with oblique rotation)

Item no.	Factor loading						
	Student cohesiveness	Teacher support	Involvement	Investigation	Task orientation	Cooperation	Equity
11	0.55						
12	0.53						
13	0.54						
14	0.73						
15	0.55						
17	0.61						
19		0.72					
20		0.76					
21		0.73					
22		0.61					
23		0.79					
24		0.83					
25		0.65					
26		0.49					
27			0.68				
28			0.83				
30			0.54				
31			0.45				
32			0.48				
34			0.33				
35				0.72			
36				0.56			
37				0.83			
38				0.61			
39				0.80			
40				0.76			
41				0.74			
42				0.73			
43					0.72		
44					0.70		
45					0.61		
46					0.65		
47					0.72		
48					0.63		
49					0.67		
50					0.65		
51						0.56	
52						0.63	
53						0.67	
54						0.64	
55						0.64	
56						0.74	
57						0.66	
58						0.54	
59							0.65
60							0.72
61							0.73
62							0.80

Table 1 (continued)

Item no.	Factor loading						
	Student cohesiveness	Teacher support	Involvement	Investigation	Task orientation	Cooperation	Equity
63							0.85
64							0.81
65							0.73
66							0.82
% variance	6.07	33.52	2.14	5.50	3.91	1.71	2.73
Eigenvalue	3.16	17.43	1.11	2.89	2.03	0.89	1.42

Factor loadings smaller than 0.30 have been omitted.

N=1,434 students in 71 classes.

Items 16, 18, 19, and 33 were removed from the analysis.

of 55.58%. A similar factor analysis for the attitude scale revealed that every attitude item had a factor loading above 0.30 and that the total percentage of variance for this scale was 51.78%. The factor analyses strongly support the factorial validity of the original seven-scale version of the WIHIC and the attitude scale.

The internal consistency reliability (Cronbach alpha coefficient) for each WIHIC and TOSRA scale was calculated for two units of analysis (the individual and the class mean) for the same sample of 1,434 students in 71 classes. Table 2 shows that the alpha coefficient for different WIHIC scales ranged from 0.80 to 0.93 with the individual as unit of analysis and from 0.85 to 0.99 with the class mean as the unit of analysis (Table 2). For the attitude scale, the alpha coefficient was 0.89 for individuals and 0.96 for class means (Table 2).

Following a strong tradition in past learning environment research (Fraser 1998a), the ability of each scale of the WIHIC to differentiate between the perceptions of students in different classrooms was explored using an ANOVA with class membership as the main effect. The individual was used as the unit of analysis for the sample of 1,434 students as the independent variable was a 71-level class membership variable. Statistically significant differences ($p<0.01$) between students' perceptions in different classes were found for all scales of the WIHIC. The eta^2 statistic, which represents the proportion of variance in scale scores accounted for by class membership, ranged from 0.12 to 0.30 for different WIHIC scales (Table 2).

Effectiveness of Inquiry Instruction

To explore the relative effectiveness of the two modes of instruction in the internal study, the average item mean (the scale mean divided by the number of items in a scale) was determined for each WIHIC, attitude and achievement scale for each of the instructional methods. Using the individual as the unit of analysis, effect sizes were calculated to describe the magnitude of the difference between inquiry and non-inquiry groups expressed in standard deviation units, as recommended by Thompson (1998, 2002). The effect size is the difference between the means of the two groups divided by the pooled standard deviation. These results are shown in Table 3.

Our analysis involved a one-way multivariate analysis of variance (MANOVA) with the learning environment scales (WIHIC) and student outcomes (attitudes and achievement) as the dependent variables and with the method of instruction (inquiry versus non-inquiry) as

Table 2 Internal consistency reliability (Cronbach alpha coefficient) for two units of analysis and ability to differentiate between classrooms (ANOVA results) for WIHIC and TOSRA scales

Scale	Unit of analysis	No. of items	Alpha reliability	ANOVA eta^2
Student cohesiveness	Individual	6	0.80	0.12**
	Class mean		0.85	
Teacher support	Individual	8	0.92	0.28**
	Class mean		0.98	
Involvement	Individual	6	0.86	0.23**
	Class mean		0.96	
Investigation	Individual	8	0.92	0.30**
	Class mean		0.99	
Task orientation	Individual	8	0.90	0.20**
	Class mean		0.97	
Cooperation	Individual	8	0.90	0.18**
	Class mean		0.96	
Equity	Individual	8	0.93	0.23**
	Class mean		0.98	
Attitudes	Individual	10	0.89	
	Class mean		0.96	

The sample consisted of 1,434 students in 71 classes.

The eta^2 statistic (which is the ratio of 'between' to 'total' sums of squares) represents the proportion of variance explained by class membership.

**$p<0.01$

the independent variable. Because the multivariate test using Wilks' lambda criterion yielded significant differences, the univariate ANOVA was interpreted for each scale (see the last column of Table 3.)

In terms of classroom environment, students in inquiry classes perceived a statistically significantly greater amount of Student Cohesiveness than did students in the non-inquiry classes (effect size=0.36 standard deviations). Although differences were not statistically significant for the remaining learning environment scales, small differences of around one-fifth of a standard deviation in favour of the inquiry group were found for Involvement, Task Orientation and Cooperation. Attitudes scores for the two groups (inquiry and non-inquiry) were quite similar. Students in the inquiry class scored slightly better in achievement than did students in the non-inquiry group (effect size=0.27 standard deviations), although this difference was not statistically significant.

During interviews, teachers noted that students initially struggled in the inquiry classes to design appropriately-controlled experiments. However, as the treatment period progressed, students became more and more familiar with the overall process and required less prompting from the teachers. The Static Electricity activity was a notable turning point for many students. Students in the inquiry classes not only explored a wider range of materials, but class discussions were also more in-depth. One group of students, for instance, made the connection that insulators were the best materials to use to create a static charge. Such leaps in content knowledge were not apparent in the non-inquiry classes during class discussions.

Overall, students in the inquiry class appear to have benefited somewhat from the instructional method. The lack of statistically significant results in part could be attributable to the relatively small sample size and the low statistical power associated with small samples available in the internal study.

Table 3 Average item mean, average item standard deviation, and difference between instructional methods (effect Size and MANOVA results) for each learning environment and outcome scale using the individual as the unit of analysis

Scale	Average item mean[a]		Average item standard deviation		Difference	
	Inquiry	Non-inquiry	Inquiry	Non-inquiry	Effect size	*F*
Learning environment						
Student cohesiveness	3.53	3.33	0.47	0.62	0.36	1.53**
Teacher support	2.73	2.80	0.95	0.85	−0.07	0.68
Involvement	2.59	2.40	0.78	0.95	0.22	1.18
Investigation	2.57	2.52	0.92	0.93	0.05	0.57
Task orientation	3.41	3.26	0.69	0.62	0.23	1.20
Cooperation	3.28	3.16	0.62	0.70	0.18	1.08
Equity	3.30	3.23	0.82	0.82	0.09	0.73
Student outcomes						
Attitudes	2.68	2.66	0.76	0.73	0.03	0.39
Achievement	5.71	5.28	1.48	1.75	0.27	1.31

Effect size is the difference in means expressed in standard deviation units.

N=165 students in 8 classes.

**$p<0.01$

[a] Average item mean=scale score divided by the number of items in that scale.

Differential Effectiveness of Instructional Methods for Different Genders

Whereas the analyses reported in the previous section explored differences between the two instructional groups for the whole sample, the purpose of the analyses reported in this section was to investigate whether the two methods of instruction (inquiry and non-inquiry) were differentially effective for males and females. This involved examining the interactions between instructional method and gender for each learning environment, attitude and achievement scale for the sample of 165 students in 8 classes who participated in the internal study. We undertook a two-way MANOVA for which the two independent variables were method of instruction and student gender. Because the multivariate test using Wilks' lambda criterion yielded significant differences for the two main effects and for the interaction, the univariate ANOVA was interpreted for each scale (see Table 4). Students perceived statistically significantly greater Student Cohesiveness in the inquiry environment (as previously noted in Table 3). Significant gender differences existed for Student Cohesiveness, Teacher Support, Investigation, Cooperation, and Attitudes (Table 4). Relative to males, females perceived more Student Cohesiveness and Cooperation, and less Teacher Support and Investigation. Females also had significantly less positive attitudes toward the class than did males.

A statistically significant interaction ($p<0.05$) between instructional method and gender emerged for four of the nine dependent variables, namely, Task Orientation, Cooperation, Equity, and Attitudes (shown graphically in Fig. 1). Therefore, the independent interpretations of instructional method differences and gender differences are valid for all scales except these four. Males in the non-inquiry group had lower Task Orientation, Cooperation, Equity, and Attitudes scores than did males in the inquiry group. In contrast, females in the non-inquiry group had higher Equity and Attitudes scores and similar levels of Task Orientation and Cooperation as did the females in the inquiry group. This suggests

Table 4 Two-way MANOVA results (F and eta^2) for instructional method and gender for each scale of the WIHIC and two student outcomes (attitudes and achievement)

Scale	Two-way ANOVA results					
	Method of instruction		Gender		Method of instruction × gender	
	F	Eta^2	F	Eta^2	F	Eta^2
Learning environment						
Student cohesiveness	5.73*	0.03	6.54*	0.04	0.57	0.00
Teacher support	0.09	0.00	4.74*	0.03	1.82	0.01
Involvement	2.32	0.01	3.85	0.02	0.81	0.01
Investigation	0.20	0.00	6.12*	0.04	0.74	0.01
Task orientation	2.75	0.02	0.00	0.00	4.29*	0.03
Cooperation	1.88	0.01	5.46*	0.03	4.57*	0.03
Equity	0.71	0.00	1.58	0.01	6.95**	0.04
Student outcomes						
Attitudes	0.20	0.00	4.84*	0.03	6.69*	0.04
Achievement	2.76	0.02	1.92	0.01	0.40	0.00

Eta^2 represents the proportion of variance in a dependent variable explained by an independent variable.

N=165 students in 8 classes.

*$p<0.05$

**$p<0.01$

that, overall, classroom environment perceptions and attitudes were more positive for males in the inquiry group, but were more positive for females in the non-inquiry group (Fig. 1).

Interviews with students and observations made by teachers revealed some interesting insights into these patterns. Males were enthusiastic about being able to devise their own experiments in the inquiry group, often going beyond the scope of a basic experiment to incorporate additional exploration. This was increasingly evident as the activities progressed and students became more comfortable with designing their own experiments. During the Static Electricity activity, for instance, students were given a set of objects to use in an attempt to create static charges. In the inquiry classes, students explored many materials that were beyond those given to them. They used window panes, tabletops, and even ceiling tiles. In the non-inquiry classes, where students were guided through the

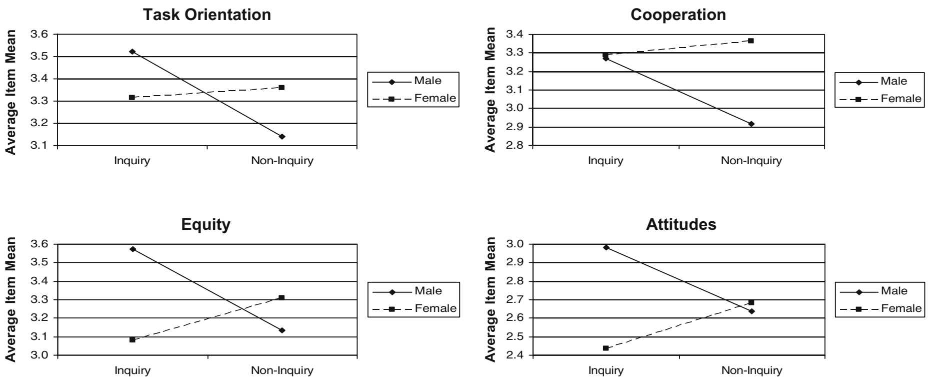

Fig. 1 Instructional method by gender interactions for three learning environment scales and attitudes

activity, only the materials given to the students had been tested and, although the data sheet left room for an additional object to be tested, almost no groups took up this option. The exploration in the inquiry group was more extensive in this way than in the non-inquiry group.

Females seemed particularly concerned about doing the experiment correctly in the inquiry classes. The teachers simply probed with questions to determine the reasoning behind the controlling of variables and procedures and, although the processes seemed sound, females wanted to know if they were correct in their setup. This uncertainty among females in the inquiry classes was a recurring theme, despite the appropriate results that they would receive from their own work. Confidence in this area rose slowly among females in the classes and the frustration seems to have led to lower attitudes scores for females in the inquiry classes as compared to females in the non-inquiry classes, where procedures and guidelines were clearly spelled out.

Also, because of the openness of the inquiry activities, males were likely to try explorations that could be potentially disruptive or dangerous, such as climbing on tables to reach the ceiling tiles. Because males required some extra attention to ensure safety, females could have perceived a lack of equity, as noted by the students themselves during interviews.

Associations Between Classroom Environment and Student Outcomes

Associations between student perceptions of the classroom environment and student outcomes (attitudes and achievement) were investigated through simple correlation and multiple regression analyses for two units of analysis (the individual student and the class mean). Results are reported in Table 5. Whereas the simple correlation describes the bivariate association between each outcome and each learning environment scale, the multiple regression analyses portray the joint influence of correlated environment scales on each outcome. The regression weights indicate which individual environment scales are related to an outcome when the other six environment scales are mutually controlled.

Table 5 shows that each of the seven scales of the WIHIC was correlated positively and significantly ($p<0.01$) with student attitudes with both the individual or the class mean as the unit of analysis. The multiple correlation of the set of seven WIHIC scales with attitudes was statistically significant at each level of analysis. With the individual as the unit of analysis, six WIHIC scales (Teacher Support, Involvement, Investigation, Task Orientation, Cooperation, and Equity) were significant independent predictors of student attitudes. With the class mean as the unit of analysis, four WIHIC scales (Student Cohesiveness, Teacher Support, Investigation, and Cooperation) were significant independent predictors of student attitudes.

Statistically significant correlations ($p<0.05$) existed between three scales of the WIHIC (Investigation, Task Orientation, and Equity) and achievement with the individual as the unit of analysis (Table 5). There were no significant simple correlations with achievement at the class level. At the student level of analysis, the multiple correlation of the set of all WIHIC scales with achievement was statistically significant, and Teacher Support, Task Orientation, Equity, and Cooperation were significant independent predictors of achievement. The multiple correlation at the class level was not statistically significant for achievement (and therefore the regression weights for individual WIHIC scales were not further examined and interpreted).

It is noteworthy that, for the statistically significant associations between an outcome and a classroom environment scale reported in Table 5, all significant simple correlations

Table 5 Simple correlation and multiple regression analyses for associations between two student outcomes (attitudes and achievement) and dimensions of the WIHIC for two units of analysis

Learning environment scale	Unit of analysis	Association			
		Attitudes		Achievement	
		r	*β*	*r*	*β*
Student cohesiveness	Individual	0.31**	0.03	0.05	0.06
	Class	0.62**	0.28**	0.03	0.27
Teacher support	Individual	0.62**	0.29**	−0.00	−0.15**
	Class	0.77**	0.45**	−0.13	−0.65*
Involvement	Individual	0.57**	0.14**	0.05	0.03
	Class	0.75**	−0.25	−0.07	0.08
Investigation	Individual	0.57**	0.21**	0.06*	0.04
	Class	0.81**	0.64**	−0.05	0.19
Task orientation	Individual	0.56**	0.23**	0.08**	0.08*
	Class	0.68**	0.14	−0.10	−0.18
Cooperation	Individual	0.43**	−0.07*	0.02	−0.10**
	Class	0.65**	−0.29*	−0.12	−0.51
Equity	Individual	0.52**	0.07**	0.09**	0.16**
	Class	0.70**	−0.01	0.03	0.75**
Multiple correlation (*R*)	Individual		0.73**		0.16**
	Class		0.86**		0.42

N=1,434 students in 71 classes.

*$p<0.05$

**$p<0.01$

are positive and most significant regression coefficients are also positive. The only negative regression coefficients in Table 5 are for attitudes and Cooperation (at both levels of analysis), for achievement and Teacher Support (both levels of analysis) and Cooperation (with the student as the unit of analysis). These negative outcome-environment associations were further explored through student interviews, as reported in the next section.

Insights from Interviews

Although space doesn't permit extensive reporting of qualitative data-collection, this section gives some examples of how insights from 20 student interviews supported and clarified the results based on questionnaire data. The results in Table 3 suggest that the inquiry method facilitated a more cohesive learning environment than did the non-inquiry method. Information from student interviews were consistent with this pattern and suggested that, because students in the inquiry group were more likely to seek explanations from peers than simply to copy answers, friendships among students were built up.

The negative independent association between classroom Cooperation and student attitudes in Table 5 was explored through interviews (see Table 6) with students involved in the internal study. Some students felt that working in groups meant that one student might carry the burden of doing most of the work while others copied the answers, which leads to frustration for the student doing the work. The interview responses suggest that having more cooperation in the class possibly could lead to an unequally-shared workload, leading to less positive attitudes toward the class. This less positive attitude, however, does not affect all students, particularly those benefiting from the harder-working students.

Table 6 Summary of student interview results for students experiencing each instructional method for each learning environment and outcome variable

Learning environment scale/student outcome	Inquiry students' comments	Non-inquiry students' comments
Student cohesiveness	Students cited numerous examples of a supportive environment, in which peers helped each other to find solutions and reason through problems, and showed respect for others' opinions.	Students offered examples related more to dividing work assignments than in working as a collective and supportive team.
Teacher support	Students felt that the teacher set up the activities and left the students to figure the rest out for themselves. The teacher would approach, ask a few 'odd' questions, and leave them to their own devices. The teacher did not offer answers.	Students noticed more teacher involvement in their work, particularly in ensuring that students were following directions and not misbehaving.
Involvement	Students felt that they were more likely to explain what they wanted their team to do during activities.	Students did not offer much evidence of sharing or discussing ideas, except in terms of who should perform certain tasks.
Investigation	Students felt that they had much control over the activities. Some students felt that they had too much control.	Students felt that they were in control over the activity as far as physically manipulating objects, but they did not design their own experiments.
Task orientation	Students were eager to get to the work. Even during interviews, students were eager to share their experiences.	Students were pleased to be doing laboratory work, though some students were disinterested in actually participating. Some students felt that they could wait because another team would get the answer anyway.[a]
Cooperation	Students shared evidence of their willingness to share resources, help each other, and work as a team.	Students focused mostly on dividing the work, copying answers, or doing most of the work with little help from team members.
Equity	Students generally agreed that the teacher refused to give anyone answers, but made it a point to visit each team.	Students felt that the teacher made sure that each team was following directions.
Attitudes toward the class	Students were divided in their opinions about the impact of the style on the class. Some students, mostly males, appreciated the freedom. Other students, mostly females, would have preferred more structure. Students enjoyed having the activities more than not having them.	Students were happy to work with friends and to do activities instead of taking notes in class.
Achievement	Students generally agreed that they learned more with inquiry activities because they could explore numerous aspects of a problem instead of looking at things from a single perspective.[b]	Students generally agreed that they learned more with non-inquiry activities because they were guided by the teacher, so they allowed students to focus on learning the information without wasting time on incorrect procedures.

[a] Related to negative association between Cooperation and achievement.

[b] Related to negative association between Teacher Support and achievement.

The negative independent association between Cooperation and achievement reported in Table 5 was also explored through interviews (Table 6). Some students agreed that there is a greater chance of being distracted by other students when working in a group, which could lead them to a lesser understanding of the material. Other students, however, felt that working in a group helped them to learn more because other people were nearby and could explain any misunderstandings. More Cooperation, as also noted above, could lead to students taking answers from other students in a mixed group of high and low achievers. This could keep a student from exploring the information personally, thus leading to less understanding. In addition, the increased distraction could interrupt the focus on the laboratory activity and detract from learning the content. This is consistent with the negative independent association between Cooperation and achievement in Table 5.

Standardized regression coefficients (Table 5) show that Teacher Support is a negative, statistically significant and independent predictor of student achievement. The multiple correlation at the class level was not significant. To help to explain these negative associations, students were asked during interviews about the effect of the teacher's support during laboratory activities on how they learned from the laboratory work. Some students said that the less that the teacher was involved, then the more that they needed to take over and get the work done themselves which, they felt, helped them to learn more. This could suggest that, if a teacher is less supportive in the class environment, the student could need to increase personal effort in order to understand the material, which could lead to higher achievement scores.

Conclusions

This study provided further cross-validation of the What Is Happening In this Class? (WIHIC) questionnaire for assessing classroom learning environment among a sample of 1,434 middle-school physical science students in 71 classes. In particular, WIHIC scales exhibited sound factorial validity and internal consistency reliability and they were able to differentiate between the perceptions of students in different classrooms.

Once the validity of the WIHIC had been established, data were analyzed with a subsample of 165 students in 8 classes to answer the second and third research questions. Relative to non-inquiry laboratory activities, inquiry instruction seemed to promote significantly more student cohesiveness in the classroom (effect size of around one-third of a standard deviation). As well, inquiry-based laboratory activities were found to be differentially effective for male and female students. Whereas males benefited more from inquiry methods, females seemed to benefit more from non-inquiry approaches in terms of attitudes to science and classroom task orientation, cooperation and equity.

In order to answer our study's third research question concerning outcome-environment associations, data were analyzed for the large sample of 1,434 students in 71 classes using two units of analysis (the student and the class) and two methods of data analysis (simple correlation and multiple regression). Past research was replicated in that strong and consistent associations emerged between student attitudes and learning environment scales. However associations between achievement and learning environment were relatively weaker.

This study had some limitations. The school involved in the study was a relatively small school and, although the entire seventh grade participated, the sample size was still only 165 students. A larger sample could have permitted differences to be identified more clearly. Also the smallness of this case-study sample prevented meaningful analyses using the class mean as the unit of analysis. Because of the lack of independence of individual

students who are nested within classes, caution is needed in interpreting results based on using the student as the unit of analysis with the small 'internal' sample (Goh et al. 1995). Additionally, because a high percentage of the students in the study were Caucasian, the findings might only be generalizable to a similar group of students. Also, parental consent for interviews was exceptionally low and, although the 20 students involved represented a mix of genders, achievement scores and instructional methods, a larger and more-varied interview sample would have been preferred. Finally, our measure of achievement was limited to a relatively short test.

The small-scale inquiry laboratory activities appear to have benefited students in terms of developing a stronger support system within the class. The students worked more closely and offered advice and suggestions. Students in the inquiry class were not confined to specific directions and were often found to explore interactions in greater detail than did students in the non-inquiry group. A notable example of this took place during a laboratory activity on static electricity. Inquiry groups attempted to produce static electricity with numerous objects around the room, including clothing, cement walls, floor tiles and wooden table-tops. Non-inquiry groups, however, tested only the materials specifically listed in the directions. The data table given to the non-inquiry groups listed four objects to test and left a fifth row blank, implying an additional material. In nearly all groups, the students did not test a fifth, unlisted object. Students generally did not even question the extra row in the data table, perhaps assuming that it was a misprint in the directions.

Replication of this study of the relative effectiveness of two laboratory teaching styles is desirable. Additional physical science concepts could be included in a future study to ensure that the complete physical science curriculum is encompassed. Carrying out similar research in other science disciplines and at other age levels is likely to prove useful. Replicating this study with a larger sample of students is likely to provide more generalizeable findings about the effectiveness of inquiry instruction.

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